Radio Echo Sounding in the Shirase Glacier Drainage Basin

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白瀬氷河流域のラジオエコー探査

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要旨：東クィーンモードランド雪氷研究計画の一環として白瀬氷河流域でラジオエコー探査を行った．その結果，この流域での氷原および，基盤岩からのエコー強度の分布が得られた．得られた氷厚と，既に知られている氷床表面高度分布から基盤岩形態を求めた．白瀬氷河の近くでは，基盤岩高度は海水面高度と等しいかそれ以下であるが，内陸に入るに従って高度を増し500から1000mに達する．また，モレーンフィールドとして知られている場所では，氷床表面直下に山が存在することもわかった．一方，基盤岩からの反射エコー強度の分布から，白瀬氷河流域主流部の氷床底部には何らかの形で水が存在すること，すなわち氷温が融点になっていることを示している．この事実は，氷床の動力学考察からの予測と一致している．

Abstract: Airborne radio echo sounding was carried out in order to measure the thickness of the ice sheet in the Shirase Glacier drainage basin. From the analysis of the result obtained, the bedrock topography was estimated and it was found that the elevation of the bedrock in the upstream area of the basin was about 500–1000 m higher than sea level as predicted by preliminary works. The investigation of the echo strength reflected from the bedrock indicates that the echo in the main part of the ice flow in the basin is stronger than in the edge part. Since the strengthening of echo intensity is caused by the existence of water, the strong echo observed in the main part supports an assumption proposed from the thinning of the ice sheet that the main part of the base of the basin is wet and the ice sheet is sliding on the bedrock.

1. Introduction

In order to study ice dynamics of the ice sheet of the Shirase Glacier drainage basin, it is necessary to know ice thickness and bedrock topography of the basin. But it has been impossible to sound in such a wide area of the basin using over-snow vehicles because of difficulties of logistics and many crevasses on the ice sheet.

The first radio echo sounding using an air plane in the Shirase Glacier drainage basin was made in 1980 and the result was reported by WADA and MAE (1981) and WADA *et al.* (1982). However, this sounding was a preliminary work and the sounding area was limited to a very narrow zone. Then in 1983 the 24th Japanese Antarctic Research Expedition (JARE-24) carried out the airborne radio echo sounding in a wide range of the Shirase Glacier drainage basin as part of the 5-year Glaciological Programe in East Queen Maud Land which started in 1981.

NARUSE (1978) observed the thinning of the ice sheet in Mizuho Plateau including the Shirase Glacier drainage basin. MAE (1977), MAE and NARUSE (1978) and MAE

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(1979) proposed that the thinning was due to the basal sliding which was caused by a wet bottom of ice in the Shirase Glacier drainage basin. NAGAO *et al.* (1984) computed basal temperature in the basin and found that the basal temperature was at a melting point. The aim of this radio echo sounding was not only to measure the ice thickness but also to check whether the base was wet or not.

2. Instrument and Region of Sounding

In 1979, the National Institute of Polar Research made a 179 MHz radio echo sounder (NIPR-A sounder) to be installed in a Pilatus Porter PC-6 aircraft owned by the institute. Specifications of the NIPR-A sounder and a schematic diagram of its transmitter and reciever were reported in a previous paper (WADA and MAE, 1981). The aerial attached to the wing of Pilatus Porter PC-6 was a 3-element Yagi antenna of about 1 m length and the carrier frequency was 179 MHz. The system of the recording of A-scope was changed from a 35 mm camera to a video set by Dr. NAKAWO of JARE-24.

Since Pilatus Porter PC-6 can supply only 1 kW of electric power, the penetration depth of the radio wave of the sounder could not exceed 2000 m. The radio echo sounding was carried out in November, 1983, along the sounding routes shown in Fig. 1. The position of aircraft was determined by detecting ω-wave transmitted from several points of the world.

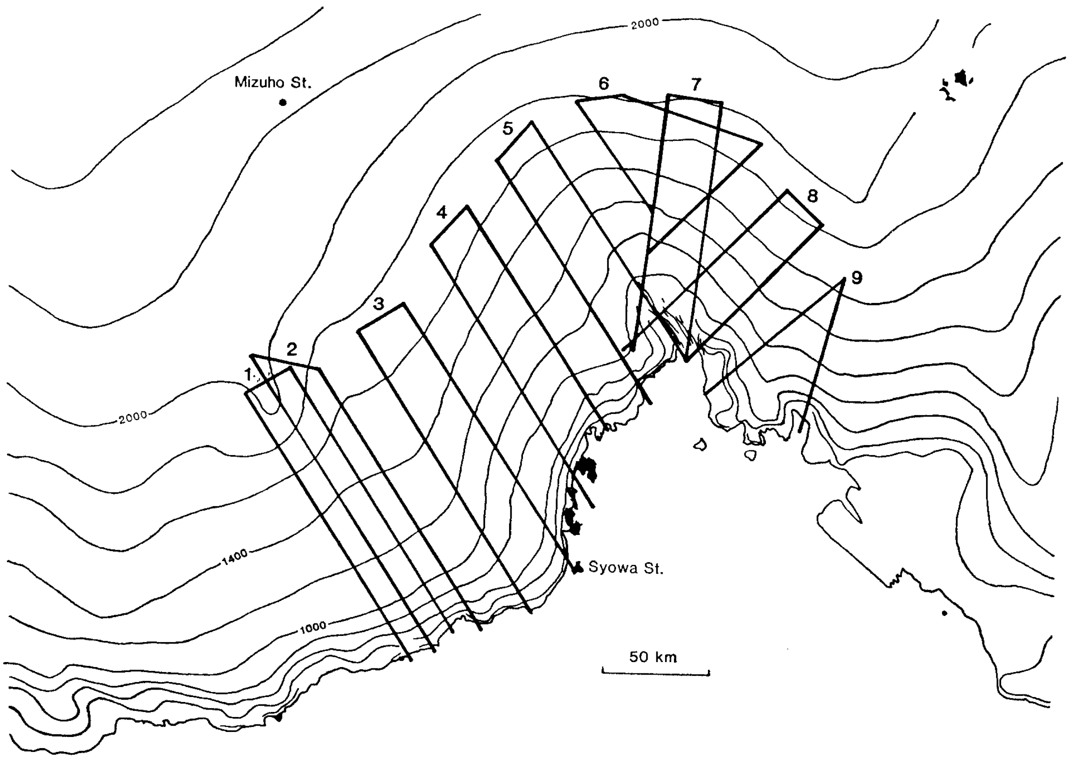


Fig. 1. The routes of the radio echo sounding in the Shirase Glacier drainage basin.

3. Result and Discussion

3.1. Bedrock topography

An example of the A-scope oscillogram of the echo intensity is shown in Fig. 2, in which T, S and R indicate echoes of transmitted wave and waves reflected from

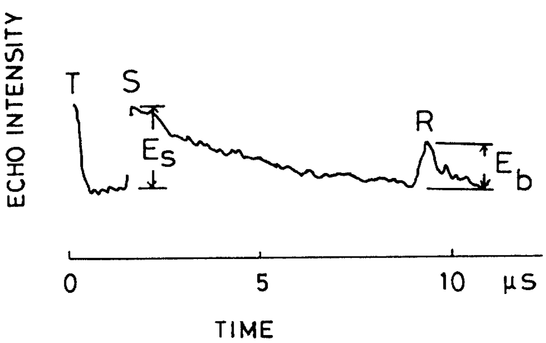
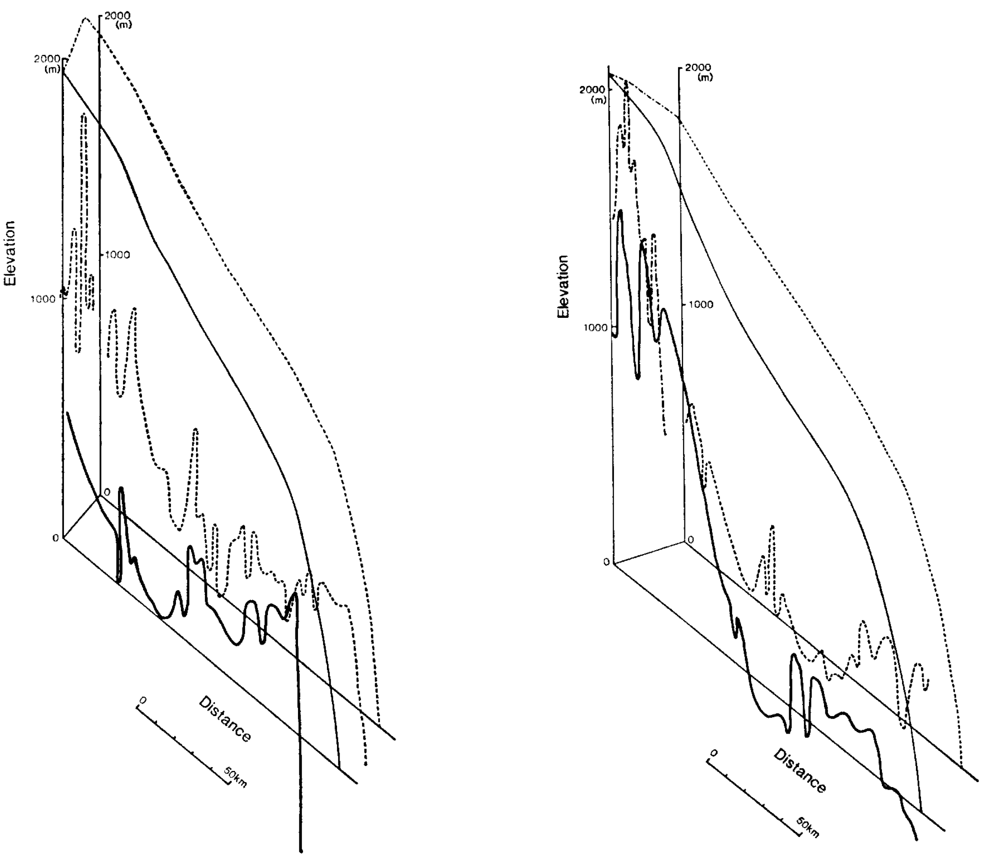
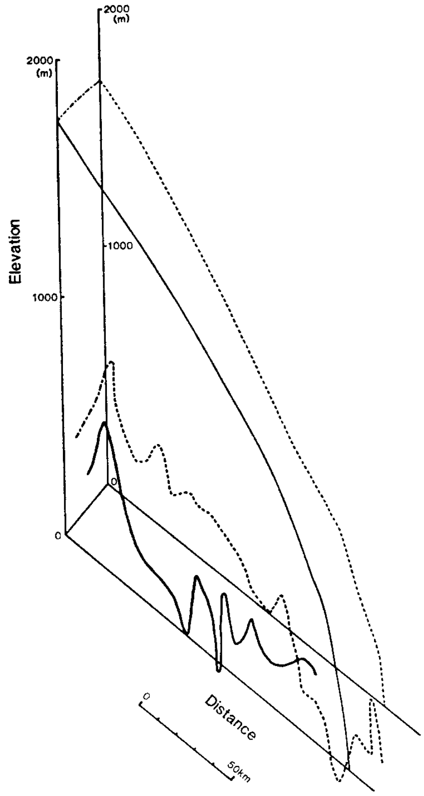


Fig. 2. A typical example of A-scope scillogram. T, S and R indicate transmitted wave and echoes reflected from the ice surface and the bedrock. E_s and E_b express the intensity of echoes from the ice surface and the bedrock.

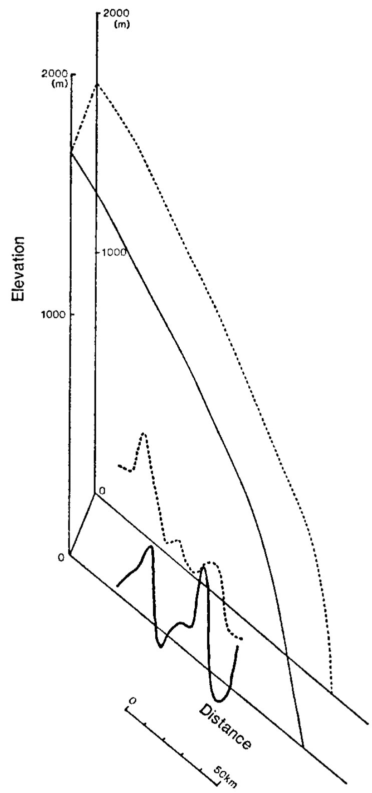


(a) route 1 *(b) route 2*

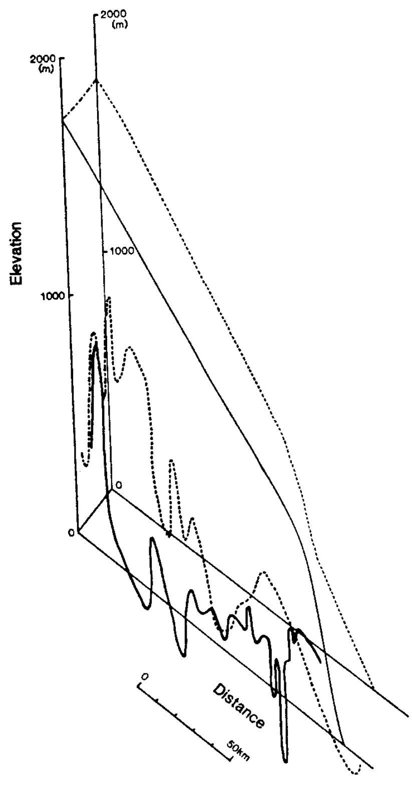
Fig. 3. The elevation the of ice surface and the bedrock. The thin lines indicate the surface profile of the ice sheet and the thick lines indicate the profile of the bedrock.



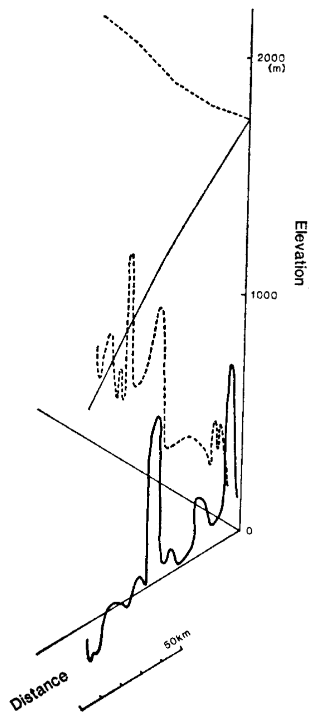
(*c*) *route 3*



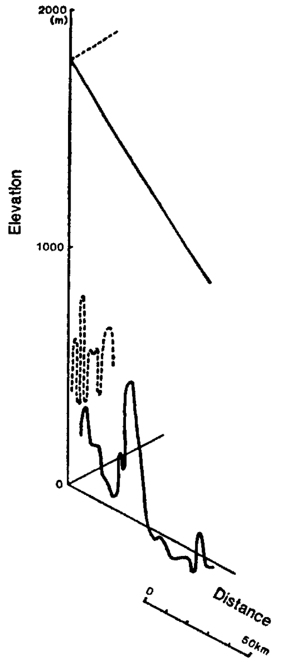
(*d*) *route 4*



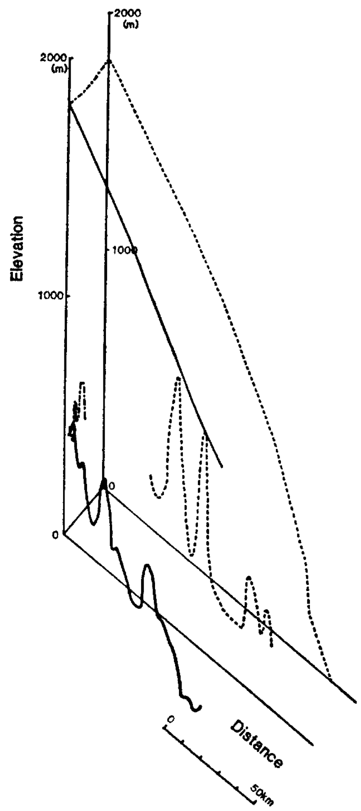
(*e*) *route 5*



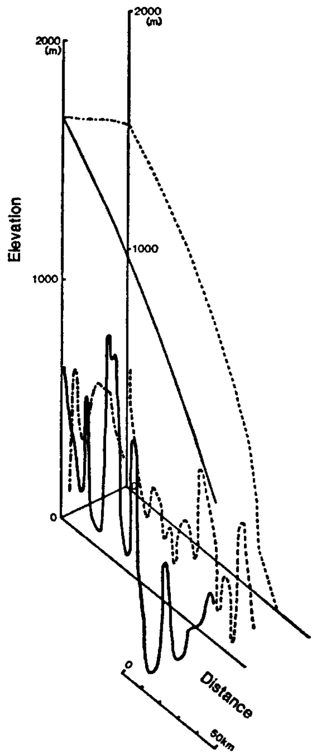
(f_1) *route 6*



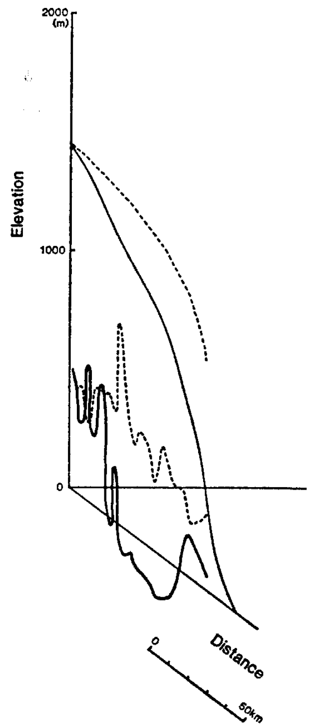
(f_2) *route 6*



(*g*) *route 7*



(*h*) *route 8*



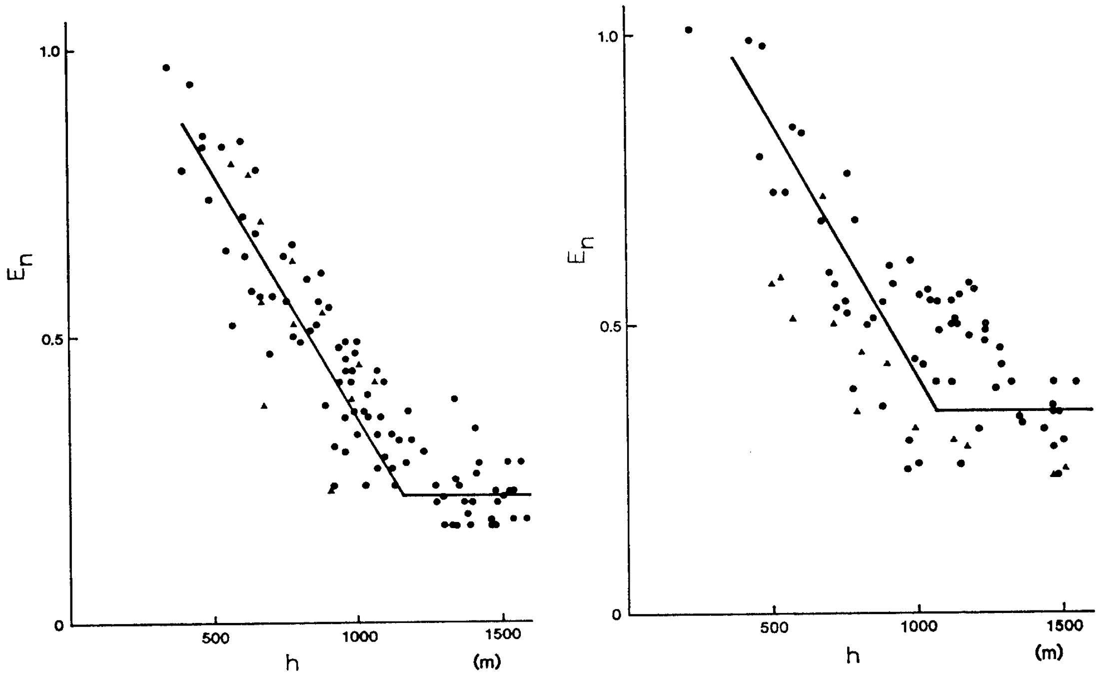
(*i*) *route 9*

the ice surface and the bedrock respectively. The ice thickness is calculated from the echo time from the bedrock using the value of wave velocity 169 m/μs in ice (ROBIN *et al.*, 1969). Using the ice thickness calculated and the surface elevation in the Shirase Glacier drainage basin compiled by MORIWAKI of the National Institute of Polar Research, the bedrock elevation was estimated along the sounding route as shown in Fig. 3 in which the profiles of ice surface and bedrock along each route shown in Fig. 1 are indicated by thin and thick lines respectively. The straight lines of the routes in Fig. 1 correspond to three kinds of line, —, --- and -·-·-, in Fig. 3. Figure 3 indicates that the bedrock elevation is definitely higher than sea level in the upstream region of the basin. This result is consistent with the fact pointed out by WADA and MAE (1981).

As shown in Figs. 3a and 3b, the elevation of the bedrock becomes as high as near the ice surface around the south end of the sounding routes 1 and 2. Those features prove the existence of subglacial mountains which has been presumed from the findings of bare ice and rock debris covering the area.

3.2. Intensity of echo reflected from bedrock

Since the intensity echo reflection from the ice surface is approximately constant, a ratio $E_n=E_b/E_s$ (E_b and E_s are the echo intensity reflected from the bedrock and the ice surface respectively as shown in Fig. 2) is introduced in order to express the normalized intensity of echo reflected from the bedrock. Fig. 4 shows the relation between E_n and ice thickness h. Comparing Fig. 4a with Fig. 4b, it can be seen that E_n at a depth deeper than about 1000 m of route 5 is larger than that of route 1. In Fig. 5,



(*a*) *route 1* (*b*) *route 5*

Fig. 4. The relation between the normalized intensity of echo reflected from bedrock, E_n, and ice thickness, h.

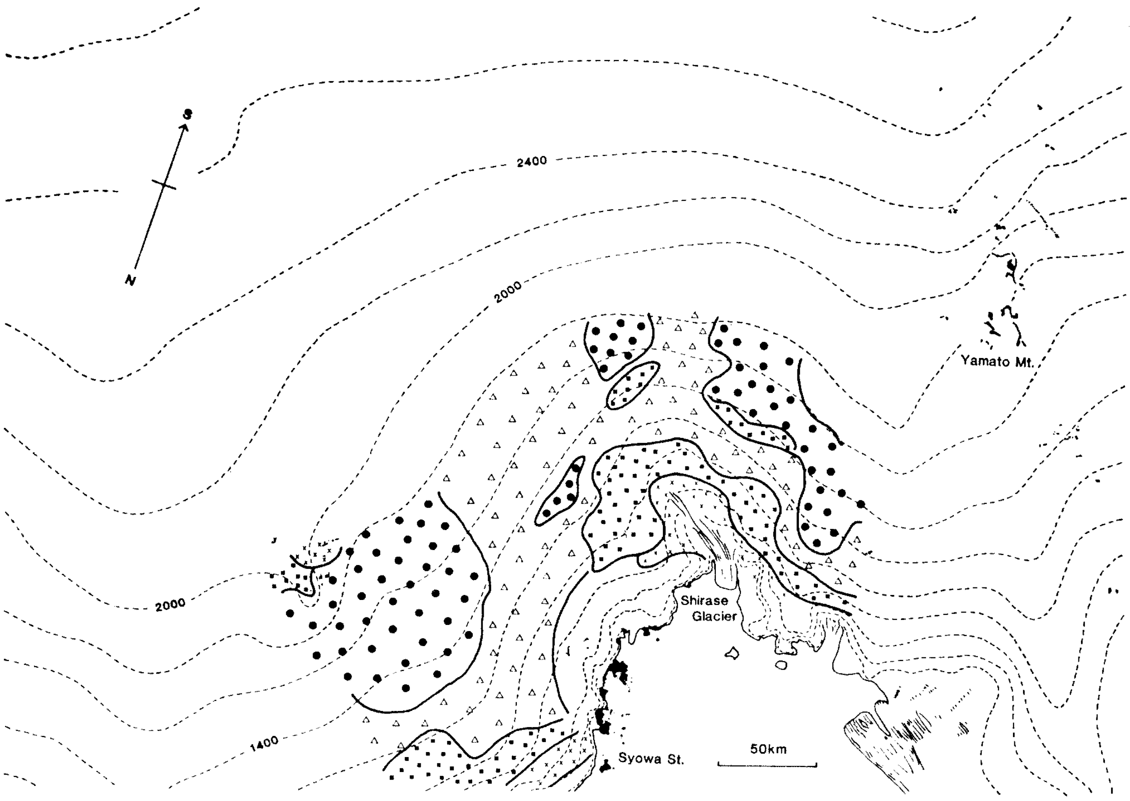


Fig. 5. The distribution of E_n, × indicates $E_n > 0.7$, ■ indicates $0.5 < E_n \leq 0.7$, △ indicates $0.3 < E_n \leq 0.5$, ● indicates $E_n \leq 0.3$.

the distribution of E_n is shown. Considering the flow line study of the Shirase Glacier drainage basin (NARUSE, 1978), it can be concluded that E_n is larger in the main stream of ice flow than in the edge part such as routes 1 and 2.

The exact reason of large E_n is not clear, but the wet bottom of ice may be the most plausible explanation of it. MAE (1978), MAE and NARUSE (1978) and MAE (1979) proposed that the thinning of the ice sheet of the Shirase Glacier drainage basin was caused by the basal sliding due to wet bottom of ice in the basin. Therefore, the increase of E_n observed in the main stream of the basin supports strongly the previous proposal that the bottom of ice is wet. This also supports the result of computing basal temperature carried out by NAGAO *et al.* (1984) that the basal temperature is at a melting point.

As shown in Fig. 4, the decrease of E_n with depth becomes small at a depth deeper than about 1000 m. This means that the radio wave of the NIPR-A sounder can penetrate ice mass deeper than 2000 m contrary to the previous observation (WADA and MAE, 1981). Therefore, if the instrument is improved, it may be expected to detect echo reflected from the bedrock deeper than 2000 m.

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